Clouds and Sensitivity in AM4/CM4

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CFMIP Meeting 2019

Outline

- Clouds in AM4
  - Focus on AMIP period (1979-2016)
  - Emphasis on Satellite simulators and observational products for GCMs.

- Sensitivities of the Simulated Climate Across a Hierarchy of GFDL Models

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- Clouds in AM4

  - Focus on AMIP period (1979-2016)
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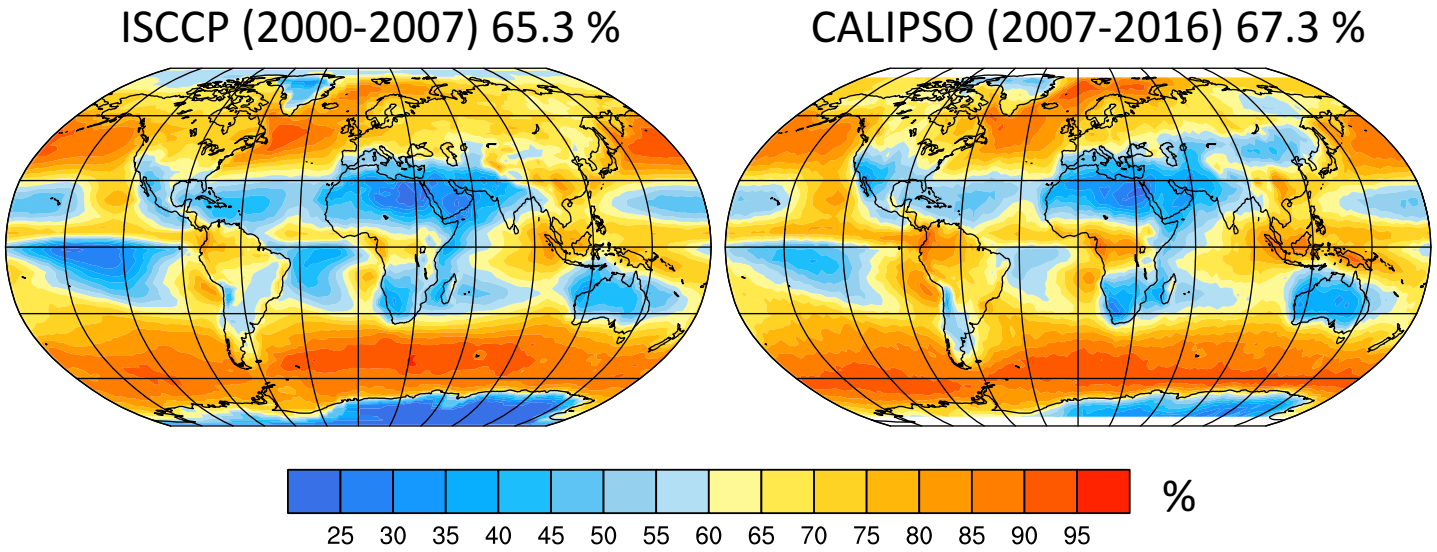
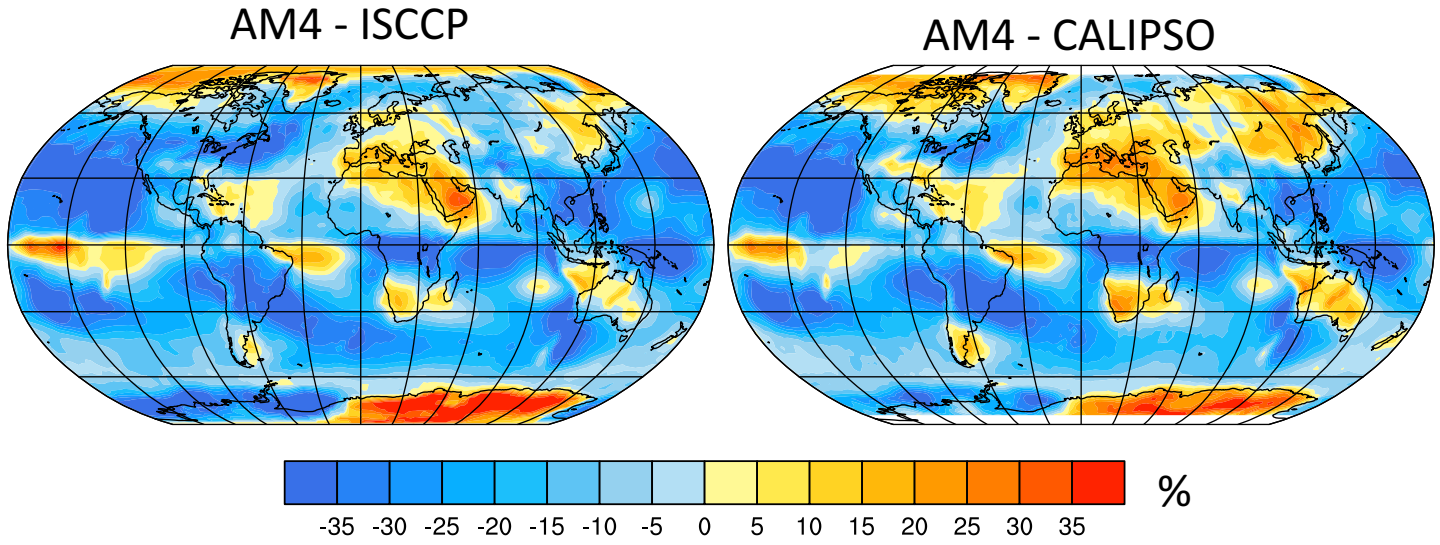
- Sensitivities of the Simulated Climate Across a Hierarchy of GFDL Models

  - AM4: Zhao et al., 2018 a,b. *JAMES*
  - CM4: Held et al., 2019 *JAMES* (in revision)
  - CM4, TCR & ECS: Winton et al., 2019 *JAMES* (submitted)

Total Cloud Fraction





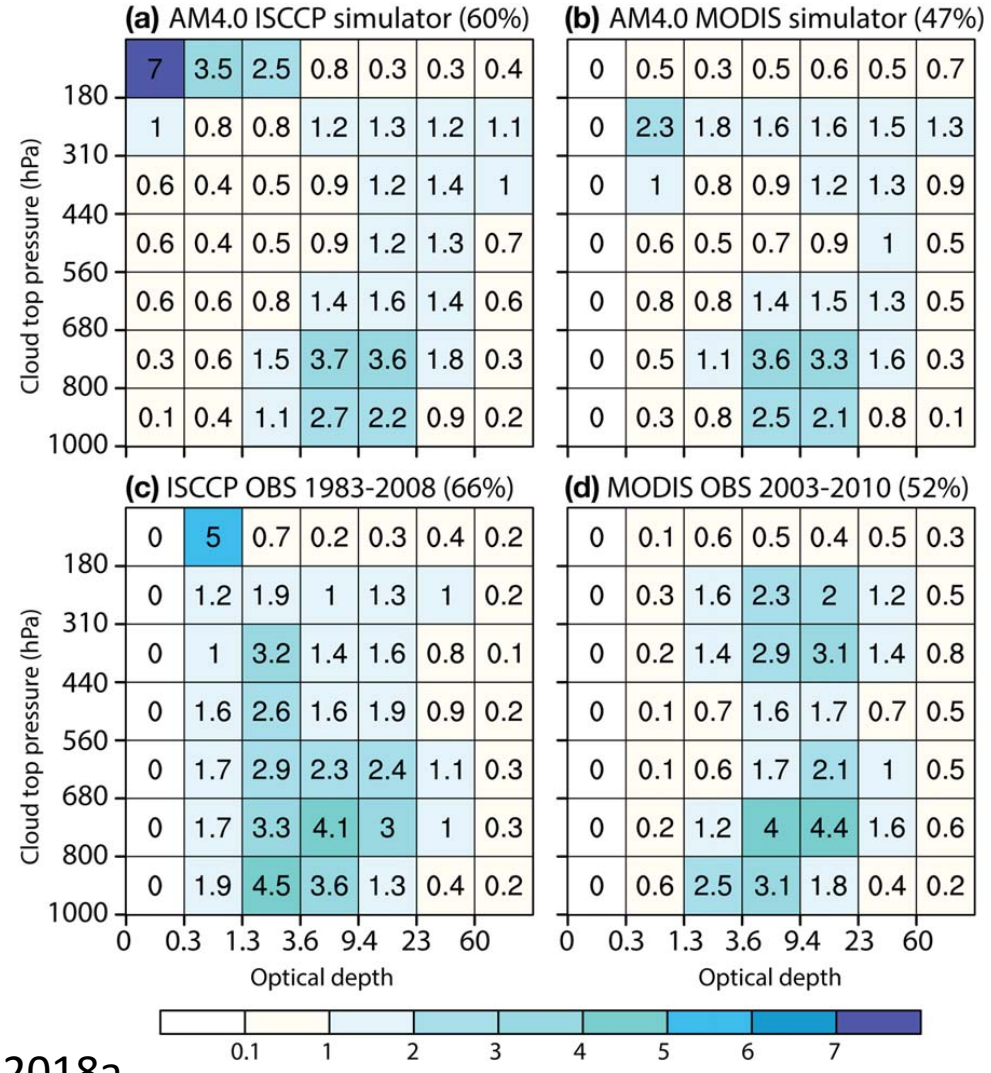
- Bias according to ISCCP: -15.2 %
- Bias according to CALIPSO: -11.89 %

- For Similar comparisons with CAM4, CAM5, and E3SM see Kay et al., 2012; Zhang et al., 2019

Cloud Fraction (%) as seen by ISCCP and MODIS

AM4 amip

Obs.

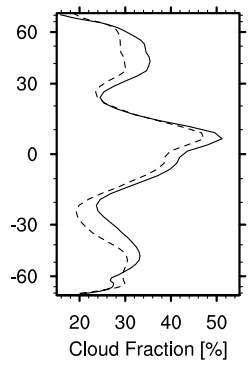


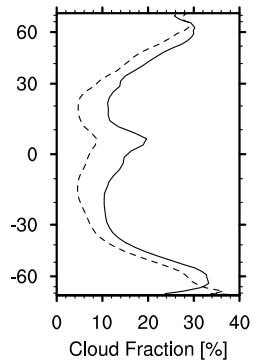
- AM4 underestimates the low-level clouds, especially the optically thin ones
- Good job with thicker low-level clouds
- Too few mid-level clouds
- Observational uncertainty is large
- This partly justifies the motivation to focus on optimizing quantities like TOA fluxes rather than cloud amount.

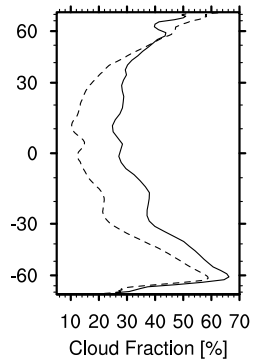
- See also Pincus et al., 2012; Klein et al., 2013

Zhao et al., 2018a

Vertical Structure of Clouds

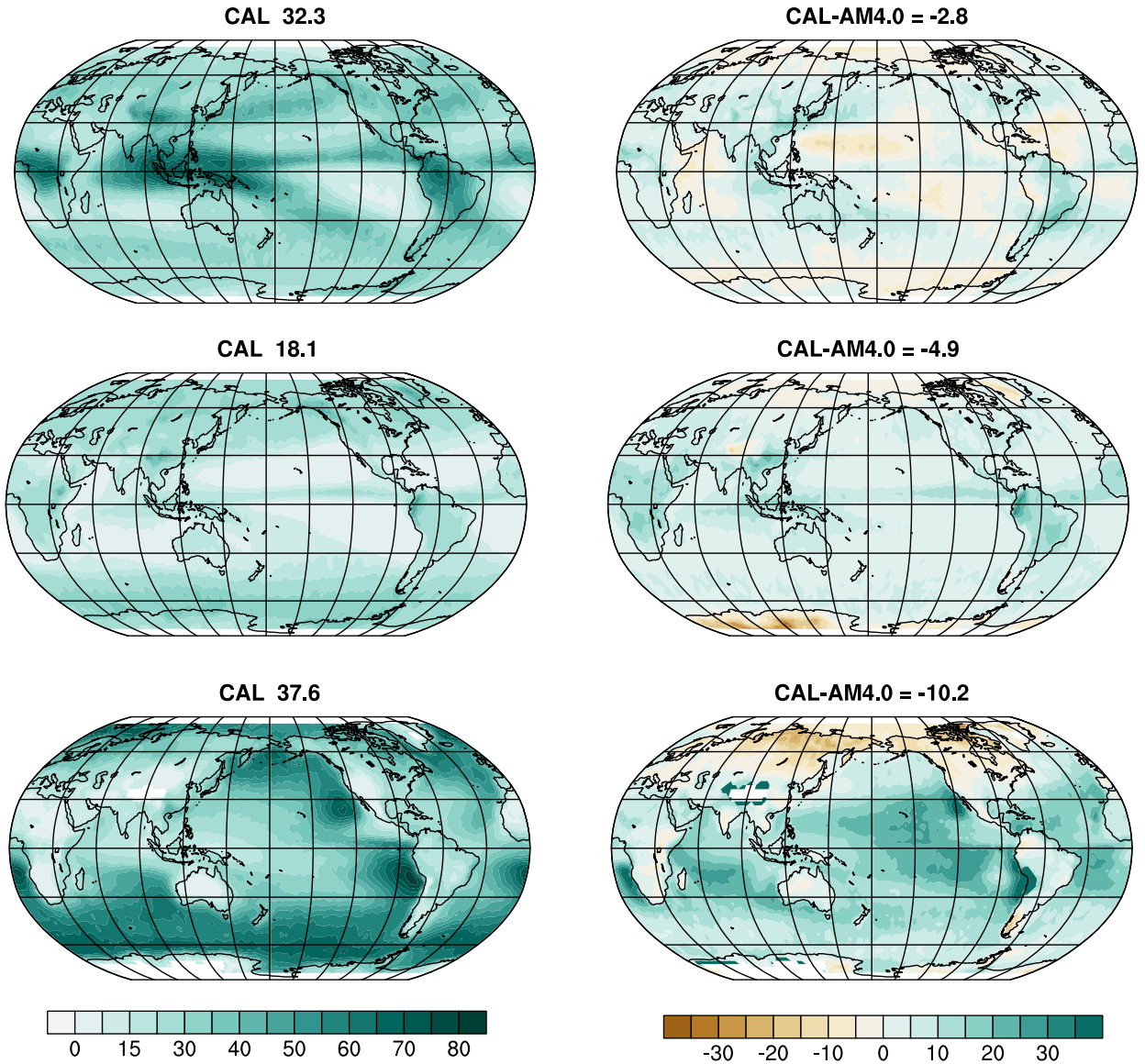






Solid: CALIPSO

Dashed: AM4.0



- CALIPSO data: 2007-2016
- Upper level bias: -2.8 %
- Mid level bias: -4.9 %
- Low level bias: -10.2 %
- Most of the issues with low level clouds are between +/- 30

Optimizing AM4 to observations

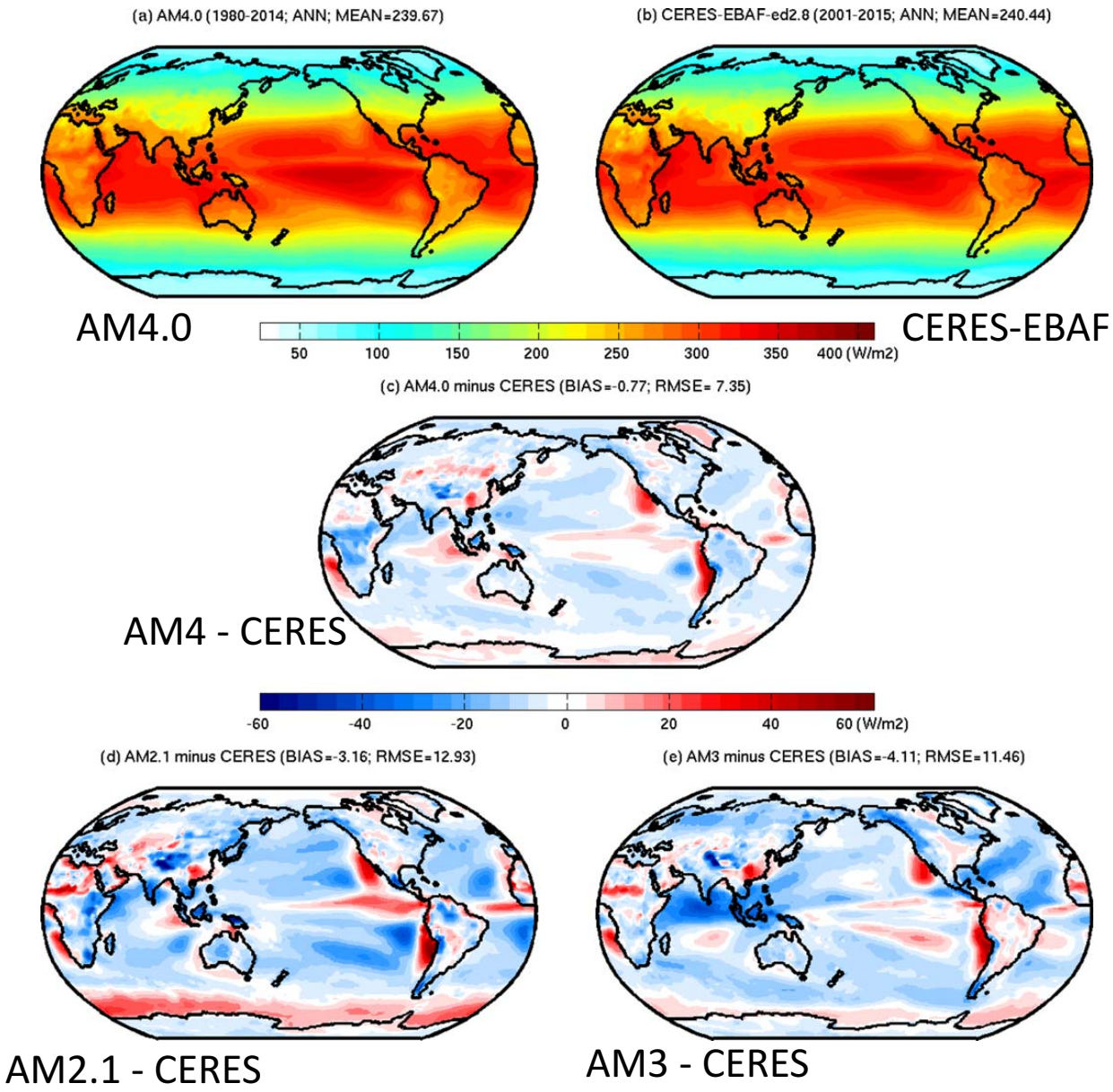
It is easy to claim that GFDL, and most other GCM have the same problems in simulating clouds as they have had for a long time.

But it is important to realize that we could simulate better clouds, such as low-level tropical clouds… if that was our number one priority.

	Bias	RMSE
AM4.0	-0.77	7.35
AM3	-4.11	11.46
AM2.1	-3.16	12.93

Zhao et al. 2018a

TOA net SW down



AM4.0 TOA radiative fluxes: Cloud Radiative Effect

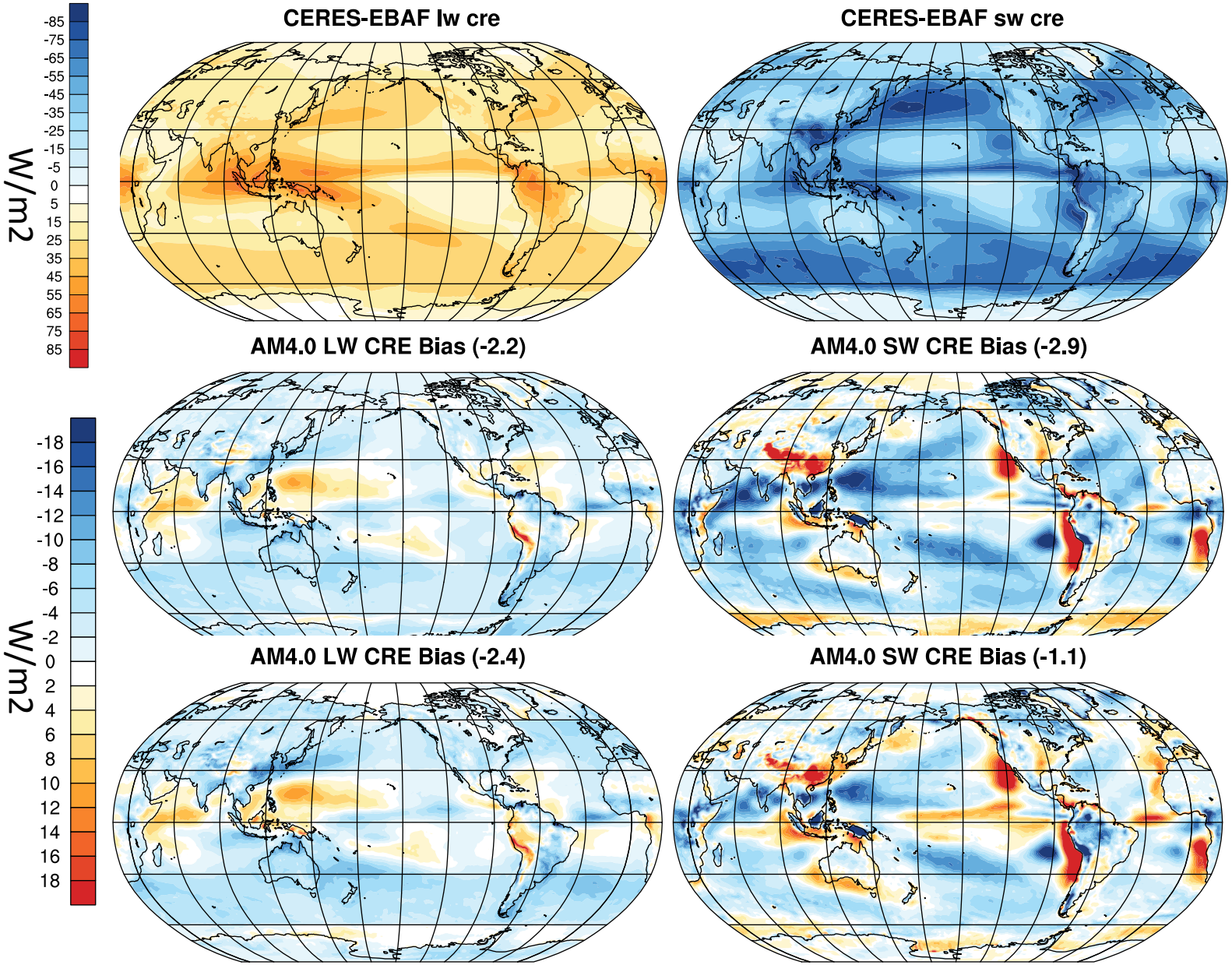
CERES v4.1

AM4-CERES v4.1

2003 – Sep 2018

AM4-CERES v2.8

2003 – Jul 2016



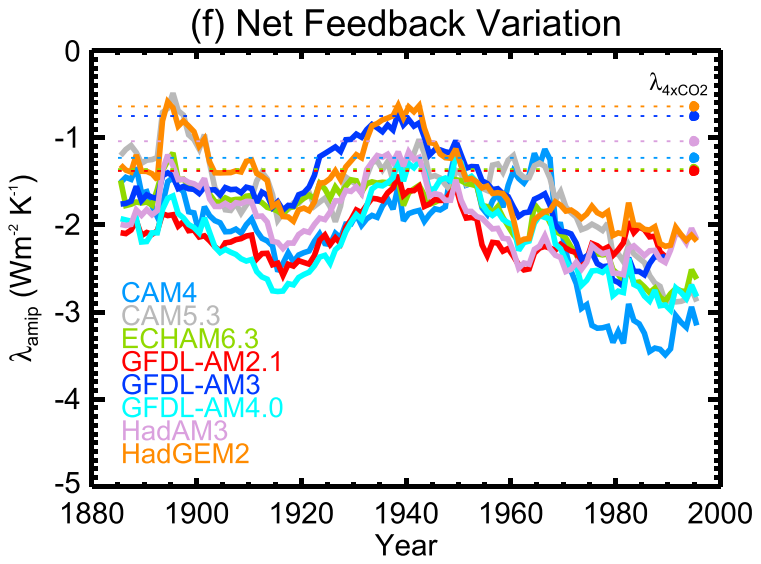
Loeb et al., 2009

Loeb and Doelling, 2018

Sensitivities of the Simulated Climate Across an ensemble of GFDL Models

- Problems with Cess (uniform +2K warming)

Cess Climate Feeback Parameter	
AM4	0.57 K W/m2
AM3	0.67 K W/m2
AM2.1	0.54 K W/m2
AM4	0.52 K W/m2 (fixed drop number)



Andrews et al., 2018

- Contrary to former expectations, the Cess Feedback Parameter (Cess Sensitivity) is not proportional to TCR, and it is not constant in time.
- The 'Pattern effect' is important. Clouds and the ocean heat uptake depend on the pattern of SST

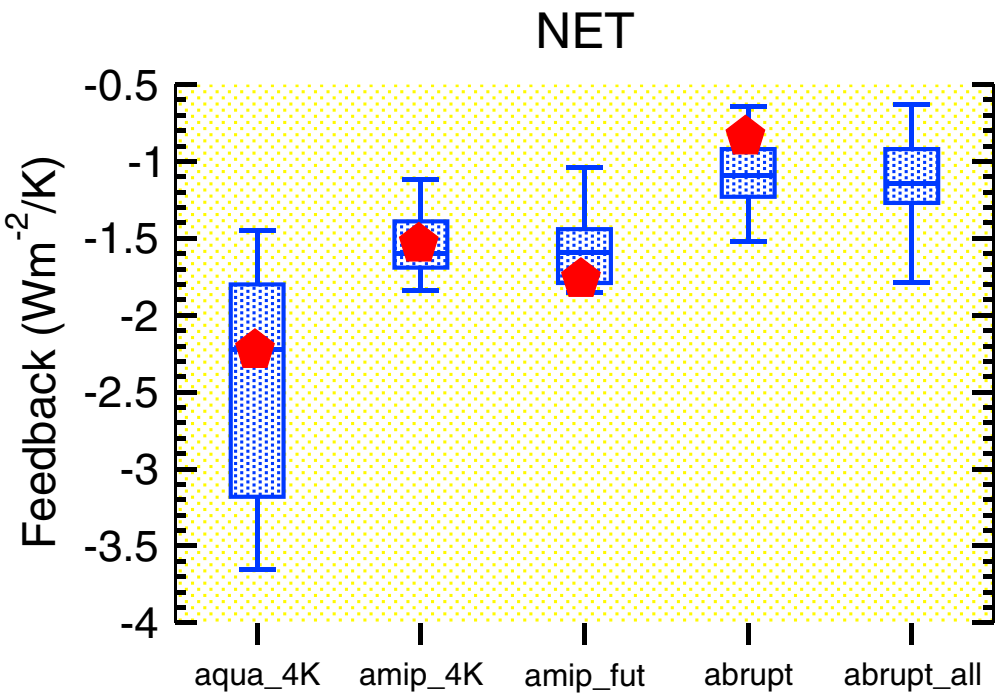
Cess et al., 1989; Senior and Mitchell, 2000; Golaz et al., 2013, Stevens et al., 2016; Gregory and Andrews, 2016; Zhou et al., 2016; Silvers et al., 2018, Andrews et al., 2018; Zhao et al., 2018 a,b

Different measures of Sensitivity: The Semantic Wars

	Cess	TCR	Eff CS (1-150)	Eff CS (51-300)	Equilibrium CS
AM4/CM4	2.1K	2.1 K	3.9 K	5.0 K	?
AM3/CM3	2.5K	2.0 K	4.0 K	4.3 K	4.8 K
AM2.1/CM2.1	2.0K	1.5 K	3.4 K	?	?
AM4*	1.9K (fixed drop number)	?	?	?	?
ESM2M		1.3 K	2.4 K	2.9 K	3.3 K

Stouffer et al., 2006; Randall et al., 2007; Andrews et al., 2012; Golaz et al., 2013; Paynter et al., 2018; Winton et al., 2019

Global and Time Mean Radiative Feedback Values

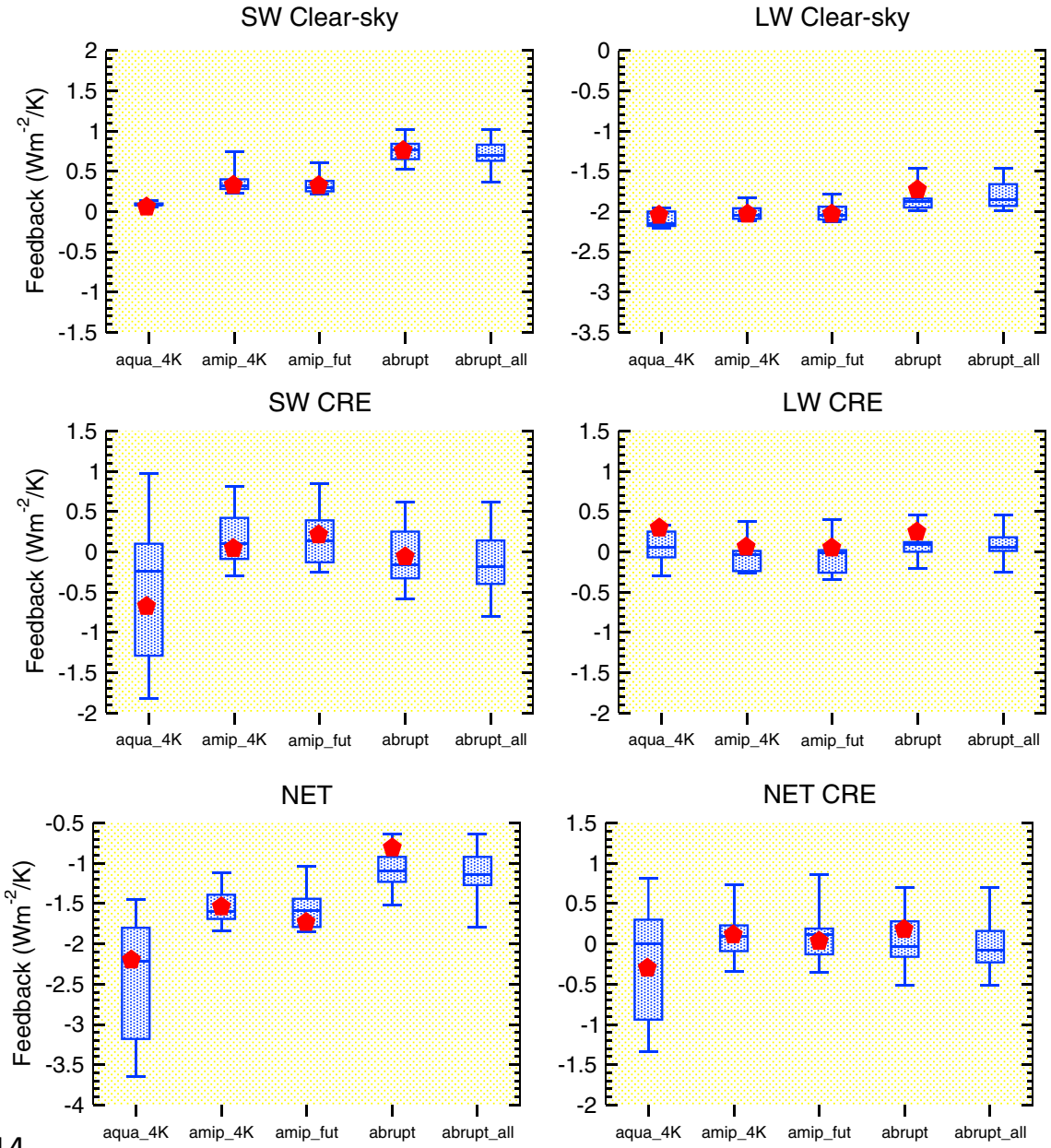


AM4p0

Initial comparison is consistent with Ringer et al. 2014

Ringer et al. 2014

Global and Time Mean Radiative Feedback Values



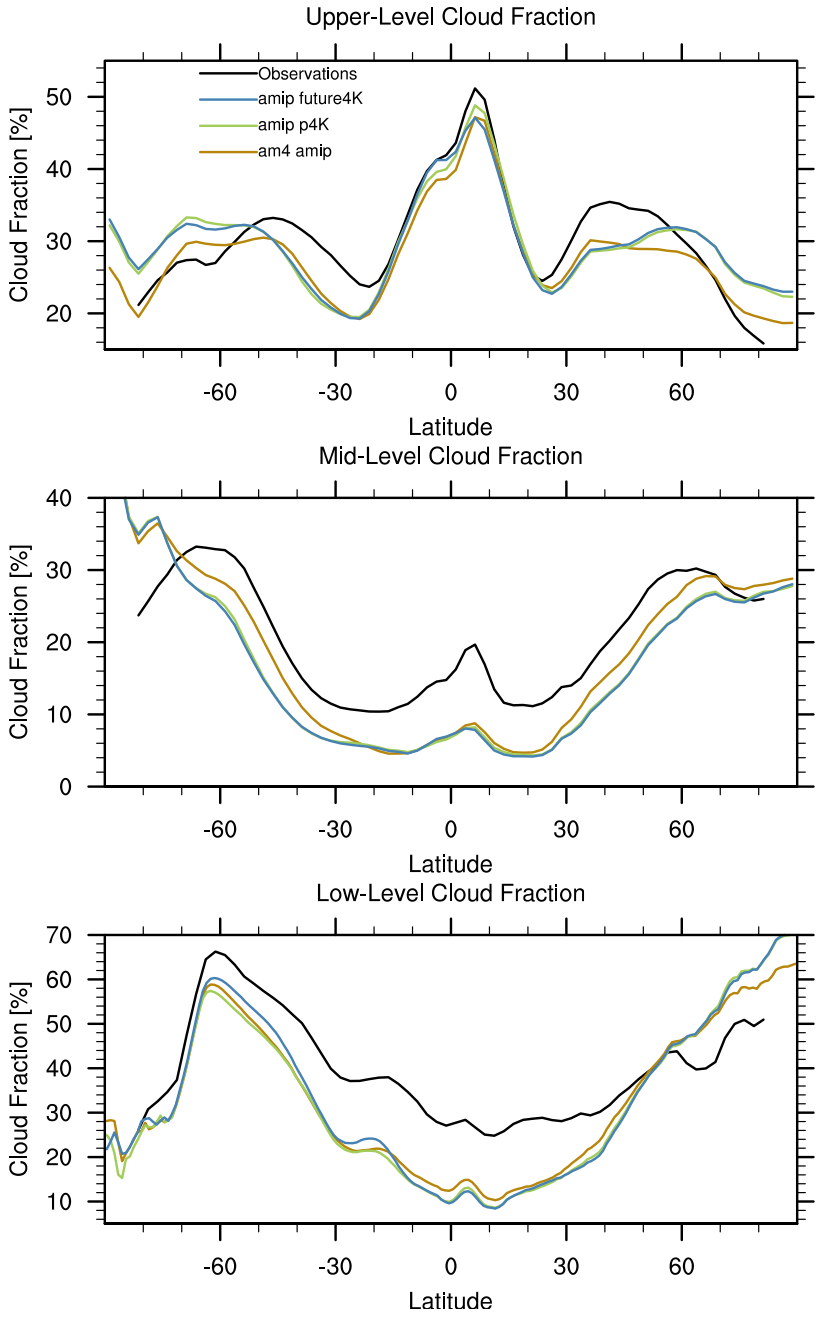
AM4p0

Initial comparison is consistent with Ringer et al. 2014

Ringer et al. 2014

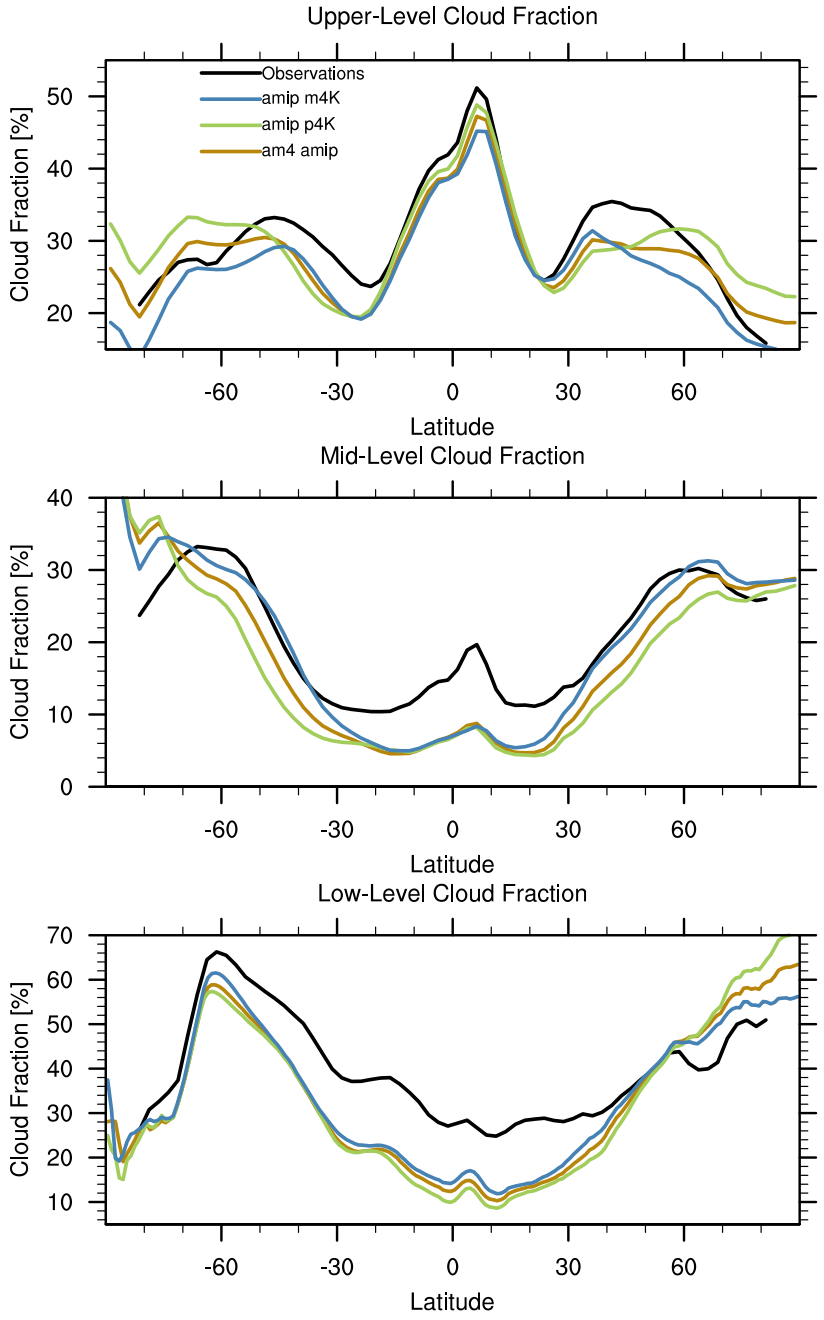
Changing clouds in *amip-future4K* and *amip-p4K*?

- Clouds are almost identical between the p4K and Future 4K experiments.
- Mid-level clouds decrease with warming at most latitudes
- Upper-level clouds increase with warming poleward of 50
- In the Tropics warming slightly increases upper level clouds and decreases low level clouds.
- Very little difference in high-latitude cloud fraction between warming experiments.



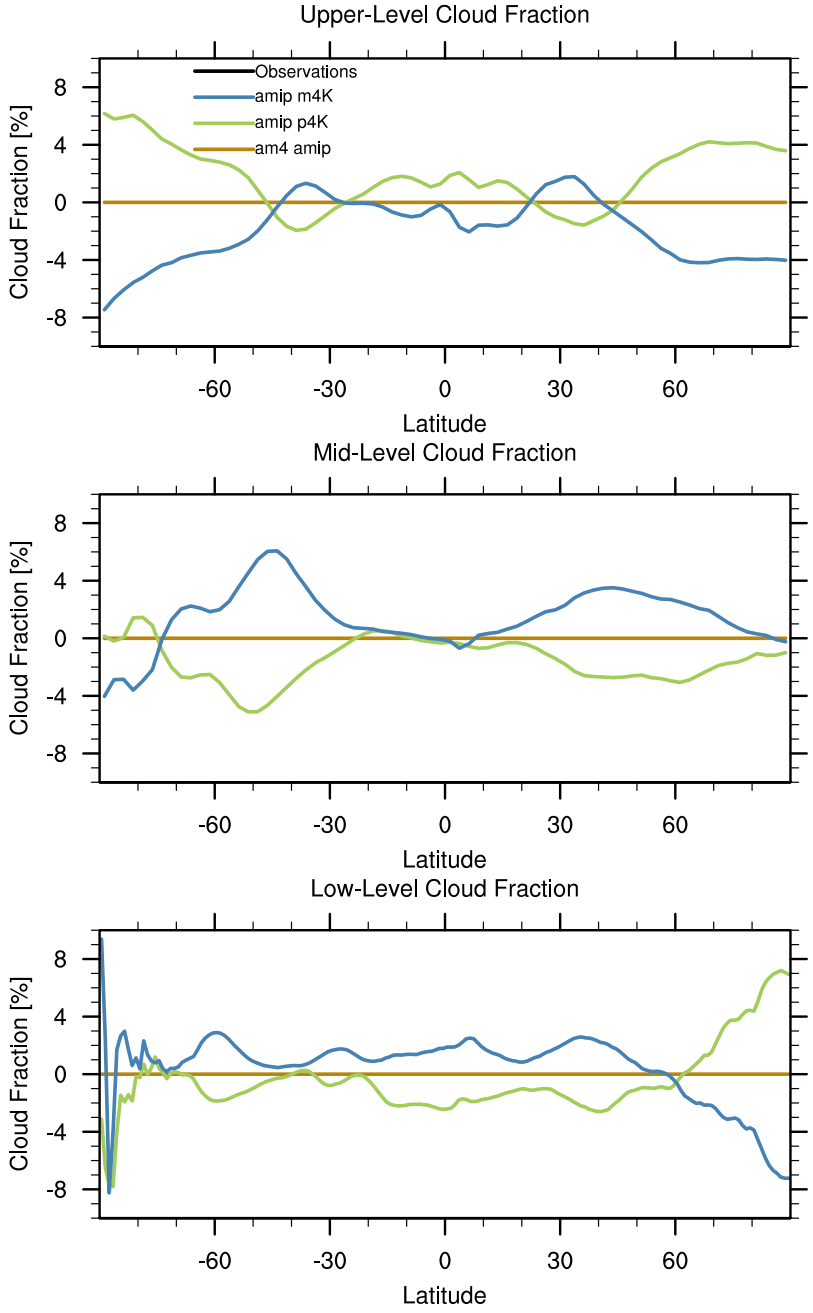
Changing clouds in *amip-p4K* and *amip-m4K*?

- The response to +/- 4K SST perturbations is fairly symmetric
- Strong polar response of clouds to SST. We don't have good observations there. Important implications for polar amplification



Relative Changes of Cloud Fraction in *amip-p4K* and *amip-m4K*

- Changes at all heights
- At mid-levels there is a lack of change in tropical clouds
- Large differences in Arctic for low-level clouds



What are we learning?

→ AM4 simulates fewer than observed clouds at most levels and latitudes but primarily in the tropical low-level clouds

→ The latest GFDL models compare very well to observed TOA radiative fluxes, clouds are less constrained

→ The pattern of warming can change the sensitivity of the climate

→The diversity of climate sensitivities can be discouraging…

→Idealized models are a critical tool for understanding cloud responses

→High sensitivity GCMs: Will things get worse before they get better?

→ Can we develop a consensus on critical cloud constraints for model developers?

Thank You

Questions about GFDL CFMIP data? Please email me.

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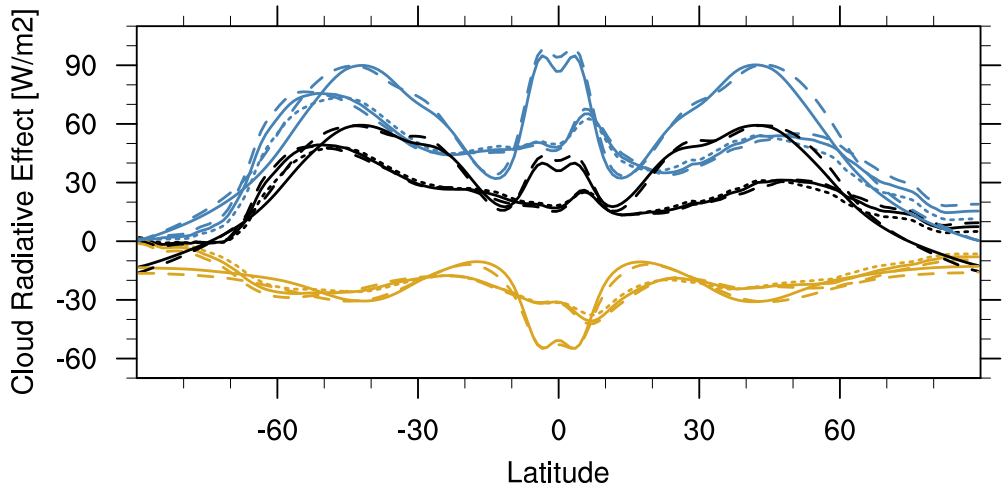
Cloud Radiative Effect



Black: Net CRE
Blue: SW CRE
Yellow: LW CRE